IN THE UNITED STATES PATENT AND TRADEMARK OFFICE
REQUEST FOR FILING NATIONAL PATENT APPLICATION

Under 35 USC 111(a) and Rule 53(b)
(Not for Provisional or PCT cases)
WITH SIGNED DECLARATION

PATENT APPLICATION

jc639 U.S. PTO 04/27/00

Asst. Commissioner of Patents
Washington, D.C. 20231

NONPROVISIONAL
NON REISSUE

jc658 U.S. PTO 09/559273 04/27/00

Sir:

Herewith is the PATENT APPLICATION of
Inventor(s): UEMURA et al.

(Our Deposit Account No. 03-3975)
Our Order No. 31317 (C#) 260548 (M#)

Title LIGHT-EMITTING SEMICONDUCTOR DEVICE USING GROUP III NITRIDE COMPOUND

Atty. Dkt.: PM 270586 (M#) F99-144-US-3 (Client Ref)

including:

Date: April 27, 2000

1. Specification: 43 pages (only spec. and claims) 2. ☐ Specification in non-English language
3. Declaration ☒ Original ☐ Facsimile/Copy ☒ Abstract 1 page(s); 26 numbered claims
3 (a). ☒ Drawings: 10 sheet(s) ☐ informal; ☒ formal of size: ☒ A4 ☐ 11"
4. This is a reissue of Patent No. _____
5. ☐ See top first page re prior Provisional, National or International application(s). ("X" box only if info is there and do not complete corresponding item 5 or 6). (Prior M# ___ SN ___)
6. **AMEND the specification** please by inserting before the first line: -- This is a ☐ Continuation-in-Part
☐ Divisional ☒ Continuation ☐ Substitute Application (MPEP 201.09) of:
6(a) ☒ National Appln. No. 09/310,974 filed May 13, 1999. (M# 260548)
6(b) ☐ International Appln. No. _____ filed _____
_____ .--
7. ☐ **AMEND the specification** by inserting before the first line: -- This application claims the benefit of U.S. Provisional Application No. 60/ _____ , filed _____ . --
8. ☒ Attached is an assignment and cover sheet. Please return the recorded assignment to the undersigned.
9. ☐ Prior application is assigned to _____
_____
by Assignment recorded _____ Reel _____ Frame _____
10. **FOREIGN** priority is claimed under 35 USC 119(a)-(d)/365(b) based on filing in Japan
11.

Application No.	Filing Date	Application No.	Filing Date
(1) 150532/1998	May 13, 1998	(2) 358549/1998	December 17, 1998
(3) 56357/1999	March 4, 1999	(4)	
(5)		(6)	
(7)		(8)	
(9)		(10)	

12. _____ (No.) Certified copy (copies): ☐ attached; ☐ previously filed (date) _____
in U.S. Application No. / _____ filed on _____

13. ☐ Attached: _____ (No.) Verified Statement(s) establishing "small entity" status under Rules 9 & 27.

14. **DOMESTIC/INTERNATIONAL** priority is claimed under 35 USC 119(e)/120/365(c) based on the following provisional, nonprovisional and/or PCT international application(s):

Application No.	Filing Date	Application No.	Filing Date
(1)		(4)	
(2)		(5)	
(3)		(6)	

15. ☐ This application is being filed under Rule 53(b)(2) since an inventor is named in the enclosed Declaration who was not named in the prior application.

16. ☒ Attached: Form PTO-1449 and cited documents

17. ☒ Preliminary Amendment: Attached

THE FOLLOWING FILING FEE IS BASED ON CLAIMS AS FILED LESS ANY ABOVE CANCELLED

				Large/Small Entity		Fee Code
18. Basic Filing Fee				$690/$345	690	101/201
19. Total Effective Claims	26	minus 20 =	*6	x $18/$9 =	+ 108	103/203
20. Independent Claims	3	minus 3 =	*0	x $78/$39 =	+ 0	102/202
*If answer is zero or less, enter "0"						
21. If any proper multiple dependent claim (ignore improper) is present , add (Leave this line blank if this is a reissue application)				+ $260/$130	+ 0	104/204
22. TOTAL FILING FEE ENCLOSED =					$798	
23. If "non-English" box 2 is X'd, add Rule 17(k) processing fee				+ $130	+ 0	139
24. If "assignment" box 6 is X'd, add recording fee				+ $40	+ 40	581
25. ☐ Attached is a Petition/Fee under Rule No.				+ $130	+ 0	122
26. TOTAL FEE ENCLOSED =					$838	

CHARGE STATEMENT: The Commissioner is hereby authorized to charge any fee specifically authorized hereafter, or any missing or insufficient fee(s) filed, or asserted to be filed, or which should have been filed herewith or concerning any paper filed hereafter, and which may be required under Rules 16-18 (missing or insufficient fee only) now or hereafter relative to this application and the resulting Official document under Rule 20, or credit any overpayment, to our Account/Order Nos. shown in the heading hereof for which purpose a duplicate copy of this sheet is attached.

This CHARGE STATEMENT does not authorize charge of the issue fee until/unless an issue fee transmittal form is filed.

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NOTE: File in duplicate with 2 post card receipts (PAT-103) & attachments

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re PATENT APPLICATION of

UEMURA et al. Group Art Unit: Unknown

Appln. No.: Unassigned Examiner: Unknown

Filed: Herewith

Title: LIGHT-EMITTING SEMICONDUCTOR DEVICE USING GROUP III NITRIDE COMPOUND

* * * * * * * * *

April 27, 2000

PRELIMINARY AMENDMENT

Hon. Commissioner of Patents
and Trademarks
Washington, DC 20231

Sir:

Please amend this application as follows:

IN THE SPECIFICATION:

Page 1, lines 5, 11-12, and 23, change "flip tip" to --flip chip--.

Page 2, line 19, change "flip tip" to --flip chip--.

Page 6., line 3, change "flip tip" to --flip chip--.

Page 11, line 13, change "flip tip" to --flip chip--.

Page 15, lines 4, 22 and 23, change "flip tip" to --flip chip--.

Page 19, line 24, change "flip tip" to --flip chip--.

Page 22, line 2, change "flip tip" to --flip chip--.

Page 25, line 13, change "flip tip" to --flip chip--.

Page 26, line 24, change "flip tip" to --flip chip--.

Page 29, line 13, change "flip tip" to --flip chip--.

Page 31, line 14, change "flip tip" to --flip chip--.

IN THE ABSTRACT:

Page 1, line 2, change "flip tip" to --flip chip--.

IN THE CLAIMS:

Claim 1, line 1, change "flip tip" to --flip chip--.

Claim 2, line 1, change "flip tip" to --flip chip--.

Claim 3, line 1, change "flip tip" to --flip chip--.

Claim 4, line 1, change "flip tip" to --flip chip--.

Claim 5, line 1, change "flip tip" to --flip chip--.

Claim 6, line 1, change "flip tip" to --flip chip--.

Claim 7, line 1, change "flip tip" to --flip chip--.

Claim 8, line 1, change "flip tip" to --flip chip--.

Claim 9, line 1, change "flip tip" to --flip chip--.

Claim 10, line 1, change "flip tip" to --flip chip--.

Claim 11, line 1, change "flip tip" to --flip chip--.

Claim 12, line 1, change "flip tip" to --flip chip--.

Claim 13, line 1, change "flip tip" to --flip chip--.

Claim 14, line 1, change "flip tip" to --flip chip--.

Claim 15, line 1, change "flip tip" to --flip chip--.

Claim 16, line 1, change "flip tip" to --flip chip--.

Claim 17, line 1, change "flip tip" to --flip chip--.

Claim 18, line 1, change "flip tip" to --flip chip--.

Claim 19, line 1, change "flip tip" to --flip chip--.

Claim 20, line 1, change "flip tip" to --flip chip--.

Claim 21, line 1, change "flip tip" to --flip chip--.

Claim 22, line 1, change "flip tip" to --flip chip--.

Claim 23, line 1, change "flip tip" to --flip chip--.

Claim 24, line 1, change "flip tip" to --flip chip--.

Claim 25, line 1, change "flip tip" to --flip chip--.

Claim 26, line 1, change "flip tip" to --flip chip--.

REMARKS

Consideration and entry of the above amendments along with an early action on the merits of this application are respectfully requested.

Respectfully submitted,

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APPLICATION UNDER UNITED STATES PATENT LAWS

Invention: LIGHT-EMITTING SEMICONDUCTOR DEVICE USING GROUP III NITRIDE COMPOUND

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<u>This is a:</u>

☐ Provisional Application

☐ Regular Utility Application

☒ Continuing Application

☐ PCT National Phase Application

☐ Design Application

☐ Reissue Application

☐ Plant Application

☐ Substitute Specification
<u>Sub. Spec.</u> filed
in App. No. _____/

☐ <u>Marked Up Specification</u> re
Sub. Spec. filed
in App. No. _____/

SPECIFICATION

LIGHT-EMITTING SEMICONDUCTOR DEVICE USING GROUP III NITRIDE COMPOUND

BACKGROUND OF THE INVENTION

Field of the invention

The present invention relates to a flip tip type of light-emitting semiconductor device that comprises layers using group III nitride formed on a sapphire substrate. Especially, the present invention relates to the device having a high luminous intensity and a low driving voltage.

Description of the Related Art

FIG. 7 shows a sectional view of a conventional flip tip type of light-emitting semiconductor 400. Each 101, 102, 103, 104, 105, 106, 120, 130, and 140 represents a sapphire substrate, a buffer layer of AlN or GaN, an n-type GaN layer, an emission layer, a p-type AlGaN layer, a p-type GaN layer, a positive electrode, a protective film, a negative electrode having a multi-layer structure, respectively. And the thick positive electrode 120 which is connected to the layer 106 is a metal layer having a thickness of 3000 Å and being formed by metals such as nickel (Ni) or cobalt (Co).

Conventionally, to reflect light emitted from an emission layer 104 toward a sapphire substrate 101 effectively, a thick metal electrode is used as a flip tip type positive electrode 120.

However, a problem persists in luminous intensity. In

the conventional device, metals such as nickel (Ni) or cobalt (Co) has been used to form the thick positive electrode 120. As a result, a reflectivity of visible (violet, blue, and green) rays whose wavelength is in the range of 380 nm to 550nm was insufficient, and the device could not obtain an adequate luminous intensity as a light-emitting semiconductor device. Therefore, further improvement has been required, as presently appreciated by the present inventors.

SUMMARY OF THE INVENTION

An object of the present invention is to obtain a light-emitting semiconductor device having a high luminous intensity and a low driving voltage.

Another object of the present invention is to obtain a light-emitting semiconductor device whose electrode has a high reflectivity and a high durability and in which the structure of electrodes is simplified.

To achieve the above objects, a first aspect of the present invention is a flip tip type of light-emitting semiconductor device using group III nitride compound semiconductor constituted by group III nitride compound semiconductor layers which is formed on a substrate and a positive electrode including at least one layer of a first positive electrode layer which is contacted to a p-type semiconductor layer and reflects light toward the substrate.

The positive electrode is made of at least one of silver (Ag), rhodium (Rh), ruthenium (Ru), platinum (Pt), palladium (Pd), and an alloy including at least one of these metals. The thickness of the positive electrode should be preferably in the range of 100 Å to 5 μm.

The second aspect of the present invention is to form a multi-layer structure made of a plural kinds of metals in the electrode described above. When the first positive electrode layer formed on or above i.e., comparatively close to the p-type semiconductor layer is made of silver (Ag), rhodium (Rh), ruthenium (Ru), platinum (Pt), palladium (Pd), and an alloy including at least one of these metals, the effect of the present invention is realized. Almost all the lower layers including the first positive electrode layer, which are placed in the range of 1000 Å below the positive electrode, should be further preferably made of metals described above.

The third aspect of the present invention is to form a first thin-film metal layer made of at least one of cobalt (Co), nickel (Ni), and an alloy including at least one of these metals between the p-type semiconductor layer and the first positive electrode layer.

The fourth aspect of the present invention is to define a thickness of the first thin-film metal layer in the range of 2 Å to 200 Å. The thickness of the first thin-film metal layer should be preferably in the range of 5 Å to 50 Å.

The fifth aspect of the present invention is to form a second thin-film metal layer made of at least one of gold (Au) and an alloy including gold (Au) between the first thin-film metal layer and the first positive electrode layer.

The sixth aspect of the present invention is to define a thickness of the second thin-film metal layer in the range of 10 Å to 500 Å. The thickness of the second thin-film metal layer should be preferably in the range of 30 Å to 300 Å.

The seventh aspect of the present invention is to define a thickness of the first positive electrode layer in the range of 0.01 μm to 5 μm. The thickness of the first positive electrode layer should be preferably in the range of 0.05 μm to 1 μm.

The eighth aspect of the present invention is to form a second positive electrode layer made of one of gold (Au) and an alloy including gold (Au) on the first positive electrode layer.

The ninth aspect of the present invention is to define a thickness of the second positive electrode layer in the range of 0.03 μm to 5 μm. The thickness of the second positive electrode layer should be preferably in the range of 0.05 μm to 3 μm, and more preferably 0.5 μm to 2 μm.

The tenth aspect of the present invention is to form a third positive electrode layer made of at least one of titanium (Ti), chromium (Cr), and an alloy including at least one of these metals the first positive electrode

layer or the second positive electrode layer.

The eleventh aspect of the present invention is to define a thickness of the third positive electrode metal layer in the range of 3 Å to 1000 Å. The thickness of the third positive electrode layer should be preferably in the range of 3 Å to 1000 Å, 10 Å to 500 Å, and more preferably, 15 Å to 100 Å, 5 Å to 500 Å.

The twelfth aspect of the present invention is to form the first positive electrode layer made of at least one of rhodium (Rh), ruthenium (Ru), and an alloy including at least one of these metalson the p-type semiconductor layer.

The thirteenth aspect of the present invention is the positive electrode having a multi-layer structure comprising following three layers: the first positive electrode layer made of at least one of rhodium (Rh), ruthenium (Ru), and an alloy including at least one of these metals; the second positive electrode layer made of one of gold (Au) and an alloy including gold (Au), formed directly on the first positive electrode layer; and the third positive electrode layer made of at least one of titanium (Ti), chromium (Cr), and an alloy including at least one of these metals, formed directly on the second positive electrode layer. The first positive electrode layer is directly connected to the p-type semiconductor layer.

The fourteenth aspect of the present invention is to define thicknesses of the first, the second, and the third positive electrode layers in the range of 0.02 μm to 2 μm,

0.05 μm to 3 μm, and 5 Å to 500 Å, respectively.

The fifteenth aspect of the present invention is a flip tip type of light-emitting semiconductor device using group III nitride compound semiconductor constituted by group III nitride compound semiconductor layers which is formed on a substrate and a positive electrode including at least one layer of a first positive electrode layer which is formed on or above a p-type semiconductor layer and reflects light toward the substrate. The positive electrode has a three-layer structure constituted by a first positive electrode layer which is made of at least one of rhodium (Rh), ruthenium (Ru), and an alloy including at least one of these metals, a second positive electrode layer which is made of titanium (Ti), chromium (Cr), and an alloy including at least one of these metals, and formed directly on the first positive electrode layer, and a third positive electrode layer which is made of gold (Au) and an alloy including gold (Au), formed directly on the second electrode layer.

The sixteenth aspect of the present invention is to form a fourth positive electrode layer which is made of at least one of titanium (Ti), chromium (Cr), and an alloy including at least one of these metals, and formed directly on the third positive electrode layer.

The seventeenth aspect of the present invention is to form an insulated protective film made of at least one of silicon oxide (SiO_2), silicon nitride (Si_xN_y), titanium

compound (Ti_xN_y, etc.), and polyamide directly on the third and the fourth positive electrode layers.

Because each of silver (Ag), rhodium (Rh), ruthenium (Ru), platinum (Pt), and palladium (Pd) has a large reflectivity R ($0.6<R<1.0$) with respect to visible (violet, blue, and green) rays whose wavelength is in the range of 380 nm to 550nm, using one of these metals or an alloy including at least one of them to form the first positive electrode layer improves a reflectivity of the positive electrode. Accordingly, the device of the present invention can obtain a sufficient luminous intensity as a light-emitting semiconductor device.

FIG. 6 illustrates a table showing characteristics of metals used in the first positive electrode layer. Details of the list are explained in the following embodiments. Judging from a various evaluations shown in FIG. 6, the five kinds of metals, i.e., rhodium (Rh), platinum (Pt), ruthenium (Ru), silver (Ag), and palladium (Pd), are proved to be best ones to form the first positive electrode layer.

Because those five metals have a large work function, a contact resistance between the p-type semiconductor layer and silver (Ag), rhodium (Rh), ruthenium (Ru), platinum (Pt), palladium (Pd), and an alloy including at least one of these metals is small. That is, a light-emitting semiconductor device having a low driving voltage can be provided by using these metals.

And because these metals are precious metal or

platinum group metal, a age deterioration for corrosion resistance against moisture, for example, is improved and an electrode of high quality can be provided by using these metals.

Although rhodium (Rh) is inferior a little to silver (Ag) concerning reflectivity, it has the same or superior characteristics compared with other metals for other characteristics. So rhodium (Rh) is proved to be one of the best metals to form the first positive electrode layer.

Also, ruthenium (Ru) has a similar or close characteristics to rhodium (Rh). So it is also proved to be one of the best metals to form the first positive electrode layer.

By forming the first thin-film metal layer, an adhesion between the the first positive electrode layer and the p-type semiconductor layer is improved, and a light-emitting semiconductor device having a more durable structure can be provided. A thickness of the first thin-film metal layer should be preferably in the range of 2 Å to 200 Å. When the thickness of the first thin-film metal layer is less than 2 Å, a firm adhesion cannot be obtained, and when more than 200 Å, a light reflectivity of silver (Ag), rhodium (Rh), ruthenium (Ru), platinum (Pt), palladium (Pd), and an alloy including at least one of these metals, which form the thick first positive electrode layer, becomes insufficient.

Further, by forming the second thin-film metal layer,

an adhesion between the first positive electrode layer and the p-type semiconductor layer is improved, and a light-emitting semiconductor device having a more further durable structure can be provided. A thickness of the second thin-film metal layer should be preferably in the range of 10 Å to 500 Å. When the thickness of the second thin-film metal layer is less than 10 Å, a firm adhesion cannot be obtained, and when more than 500 Å, a light reflectivity of silver (Ag), rhodium (Rh), ruthenium (Ru), platinum (Pt), palladium (Pd), and an alloy including at least one of these metals, which form the first positive electrode layer, becomes insufficient.

A thickness of the first positive electrode layer is in the range of 0.01 μm and 5 μm. When the thickness of the first positive electrode layer is less than 0.01 μm, an emitted light transmits through the larger without reflection and when more than 5 μm, too much time is required to form, which is not preferable for a mass production.

By forming the second positive electrode layer, the positive electrode can be provided without increasing a resistance of the thick positive electrode. To prevent an adverse effect caused by heating and cooling while forming a bump material, a gold ball, or a wire bonding, the thickness of the positive electrode should be preferably more than 0.1 μm. Because gold (Au) is a material which is easy to be formed and has a superior corrosion resistance, and because

it has strong adhesion to a bump material, a gold ball, or a wire bonding, it is preferable to use gold (Au) or an alloy including gold (Au) to form the second positive electrode layer.

A thickness of the second positive electrode layer should be preferably in the range of 0.03 μm to 5 μm. When the thickness of the second positive electrode layer is less than 0.03 μm, a sufficient effect cannot be obtained, and when more than 5 μm, too much time is required to form the electrodes.

And when the thickness of the second positive electrode layer is more than 5 μm, a thickness of a negative electrode become unnecessarily thicker in order to form a bump or a gold ball, as explained in the following third embodiment, which is not preferable.

By forming the third positive electrode layer (the fourth positive electrode layer in case of the sixteenth aspect) made of at least one of titanium (Ti), chromium (Cr), and an alloy including at least one of these metals, when an insulation layer made of, for example, silicon oxide (SiO_2), silicon nitride (Si_xN_y), or polyamide, between the positive and negative electrodes, which are formed on the opposite sides of the substrate, the insulation layer can be prevented from peeling off from the positive electrodes. Accordingly, the third positive electrode layer can prevent a bump material from short-circuiting while forming a bump. A thickness of the third positive electrode layer should be

preferably in the range of 3 Å to 1000 Å. When the thickness of the third positive electrode layer is less than 3 Å, a firm adhesion to the insulation layer cannot be obtained, and when more than 1000 Å, a firm adhesion to connecting materials such as a bump material or a gold ball cannot be obtained, which are not preferable.

Because the positive electrode having a multi-layer structure as described above has a high reflectivity and a large durability against moisture, a protection layer can be partly simplified. As a result, the positive electrode can be connected to an external electrode without using a wire bonding.

The flip tip type of light-emitting semiconductor device shown in the fifteenth aspect of the present invention differs from that of the thirteenth and the fourteenth aspect of the present invention in the constituent elements of the second and the third positive electrode layers. The semiconductor device shown in the fifteenth aspect can provide the same effect as that shown in the thirteenth and the fourteenth aspect of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

Other objects, features, and characteristics of the present invention will become apparent upon consideration of

the following description and the appended claims with reference to the accompanying drawings, all of which form a part of the specification, and wherein reference numerals designate corresponding parts in the various figures, wherein:

FIG. 1 is a sectional view of a flip tip type of light-emitting semiconductor device 100 in accordance with the first embodiment of the present invention;

FIG. 2 is a sectional view of a flip tip type of light-emitting semiconductor device 200 in accordance with the second embodiment of the present invention;

FIG. 3 is a table to compare performances of each flip tip type of light-emitting semiconductor devices 100, 200 and 400 in accordance with the second embodiment of the present invention;

FIG. 4 is a sectional view of a flip tip type of light-emitting semiconductor device 300 in accordance with the third embodiment of the present invention;

FIG. 5A is a table comparing luminous intensities of the light-emitting semiconductor device 300 explained above and the light-emitting semiconductor device 400 of prior art in accordance with the third embodiment of the present invention;

FIG. 6 is a table showing characteristics of metals used in the first positive electrode layer in accordance with the third embodiment of the present invention;

FIG. 7 is a sectional view of a light-emitting

semiconductor device 400 of a prior art;

FIG. 8 is a sectional view of a light-emitting semiconductor device 150 of the present invention;

FIG. 9 is a plan view of a light-emitting semiconductor device 500 in accordance with an embodiment of the light-emitting semiconductor device 300 shown in FIG. 4; and

FIG. 10 is a a sectional view of a flip tip type of light-emitting semiconductor device 600 in accordance with the fifth embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention will be described hereinbelow with reference to specific embodiments.

(First Embodiment)

FIG. 1 illustrates a sectional view of a flip tip type of light-emitting semiconductor device 100. The semiconductor device 100 has a sapphire substrate 101 which has a buffer layer 102 made of nitride aluminum (AlN) having a thickness of 200 Å and an n^+-layer 103 having a thickness of 4.0 μm with a high carrier concentration successively thereon.

And an emission layer 104 constructed with a multi quantum-well (MQW) structure made of GaN and $Ga_{0.8}In_{0.2}N$ is formed on the n^+-layer 103. A Mg-doped p-layer 105 made of $Al_{0.15}Ga_{0.85}N$ having a thickness of 600 Å is formed on the emission layer 104. Further, a Mg-doped p-layer 106 made of

GaN having a thickness of 1500 Å is formed on the p-layer 105.

A first thin-film metal layer 111 is formed by a metal deposit on the p-layer 106 and a negative electrode 140 is formed on the n^+-layer 103. The first thin-film metal layer 111 is made at least one of of cobalt (Co) and nickel (Ni) having a thickness about 10 Å, and is adjacent to the p-layer 106. A positive electrode (first positive electrode layer) 120 is made of at least one of silver (Ag), rhodium (Rh), ruthenium (Ru), platinum (Pt), palladium (Pd), and an alloy including at least one of them, having a thickness of about 3000 Å.

The negative electrode 140 having a multi-layer structure is formed on an exposed portion of the n^+-layer 103 of high carrier concentration. The multi-layer structure is comprising following five layers: about a 175 Å in thickness of vanadium (V) layer 141; about 1000 Å in thickness of aluminum (Al) layer 142; about 500 Å in thickness of vanadium (V) layer 143; about 5000 Å in thickness of nickel (Ni) layer 144; and about 8000 Å in thickness of gold (Au) layer 145. A protective film 130 made of SiO_2 is formed on the top surface.

As described above, when the positive electrode 120 is made of at least one of silver (Ag), rhodium (Rh), ruthenium (Ru), platinum (Pt), palladium (Pd), and an alloy including at least one of these metals, a luminous intensity is improved by about 10 % to 50 % compared with a light-

emitting semiconductor device 400 of prior arts which is shown in item number 1 and 2 of FIG. 3.

(Second Embodiment)

FIG. 2 shows a sectional view of a flip tip type of light-emitting semiconductor device 200 of the present invention. The semiconductor device 200 differs from the device 100 described in the first embodiment only in forming a second thin-film metal layer 112 on the first thin-film metal layer 111. The second thin-film metal layer 112 is made of Au having a thickness of about 150 Å, which is formed by a metal deposit after the first-thin film metal layer 111 is formed, in the same way of forming the first thin-film metal layer 111 made of cobalt (Co) or nickel (Ni) having a thickness of about 10 Å.

Forming this second thin-film metal layer 112 between the first thin-film metal layer 111 and the positive electrode (first positive electrode layer) 120 enables the positive electrode 120 to be connected to the layer 106 more firmly.

FIG. 3 shows a table to compare performances of each flip tip type of light-emitting semiconductor devices 100, 150, 200 and 400, respectively. The table of FIG. 3 also shows performances of a flip tip type of light-emitting semiconductor device, comprising a positive electrode 120 which is made of at least one of silver (Ag) and rhodium (Rh), directly contacted to the p-layer 106 without the

first thin-film layer 111 in the first embodiment, shown in FIG. 8 (item number 3, or 3.1).

As shown in this table, a luminous intensity of the light-emitting semiconductor device 100 or 200 in the present invention, which has the positive electrode 120 made of metal layers comprising at least one of silver (Ag), rhodium (Rh), ruthenium (Ru), platinum (Pt), palladium (Pd), and an alloy including at least one of these metals, is improved by about 10 % to 50 % compared with the light-emitting semiconductor device 400 of prior arts which is shown in item number 1 and 2 of FIG. 3.

Further, with respect to the light-emitting semiconductor device 400 shown in item numbers 1 and 2, a first thin-film metal layer is not formed because the positive electrode 120 itself is made of cobalt (Co) or nickel (Ni), which ensures an adhesion between the positive electrode 120 and the layer 106 sufficiently. The light-emitting semiconductor device 400 shown in item number 1 and 2 of FIG. 3, which contains the positive electrode 120 made of cobalt (Co) or nickel (Ni), has a low relative luminous intensity because a reflectivity of metal elements which constitute the positive electrode 120 is small. Accordingly, superiority or inferiority of the relative luminous intensities shown in FIG. 3 is not due to the existence of the first thin-film metal layer 111.

Conversely, when the positive electrode 120 is made of at least one of silver (Ag), rhodium (Rh), ruthenium (Ru),

platinum (Pt), palladium (Pd), and an alloy including at least one of these metals, a large luminous intensity can be obtained in case that the first or the second thin-film metal layer 111 or 112 is not existed, as understood comparing item number 3 with item numbers 4 and 8 of FIG. 3. The luminous intensity shows an excellent value although a adhesion between the positive electrode 120 and the layer 106 is inferior to some degree. That is because the first and the second thin-film metal layers 111 and 112 which absorb light do not exist.

Particularly, as shown in FIG. 8, when about 3000 Å in thickness of the positive layer 120 made of rhodium (Rh) is formed directly on a p-type GaN layer 106 in the light-emitting semiconductor device 150 without forming the first or the second thin-film metal layer, whose characteristics are shown in item number 3.1 of FIG. 3, the light-emitting semiconductor device 150 can have about the same luminous intensity as that of the light-emitting semiconductor device 200 shown in item 8. And also, an even or a firmer adhesion to the GaN layer 106 can be obtained. These are caused by a high reflectivity of rhodium (Rh) and a firm adhesion of rhodium (Rh) to the GaN layer 106 in the light-emitting semiconductor device 150. Accordingly, the light-emitting semiconductor device 150 shown in item 3.1 superior to the light-emitting semiconductor device 100 shown in item 5 of FIG. 3 at these points.

In short, manufacturing the light-emitting

semiconductor device 150 shown in item 3.1 of FIG. 3 means to be able to provide a light-emitting semiconductor device having sufficient conditions of a luminous intensity and a adhesion, because of a characteristic of rhodium (Rh), without forming the first or the second thin-film metal layer. Thus because the light-emitting semiconductor device 150 does not need a forming process of the first or the second thin-film metal layer, a sufficient mass productivity can be realized.

In the embodiment, the positive electrode 120 shown in FIGs. 1, 2 and 8 has a thickness about 3000 Å. Alternatively, the thickness of the electrode 120 can be in the range of 100 Å to 5 μm. When the thickness of the positive electrode 120 is less than 100 Å, a light reflectivity become insufficient. When the thickness is more than 5 μm, too much time and materials for deposit are required, which means that the thickness is of no use concerning a production cost performance.

In the embodiment, the first thin-film metal layer 111 has a thickness about 10 Å. Alternatively, the thickness of the first thin-film metal layer 111 can be in the range of 2 Å to 200 Å. The thickness of the first thin-film metal layer 111 should be more preferably in the range of 5 Å to 50 Å. When the thickness of the first thin-film metal layer 111 is too small, function of binding the positive electrode 120 to the GaN layer 106 is weakened, and when too large, a light absorption is occurred therein and a luminous

intensity is lowered.

In the embodiment, the second thin-film metal layer 112 has a thickness about 150 Å. Alternatively, the thickness of the second thin-film metal layer 112 can be in the range of 10 Å to 500 Å. The thickness of the second thin-film metal layer 112 should be more preferably in the range of 30 Å to 300 Å. When the thickness of the second thin-film metal layer 112 is too small, binding the positive electrode 120 to the first thin-film metal layer 111 is weakened, and when too large, a light absorption is occurred therein and a luminous intensity is lowered.

In the embodiment, the positive electrode 120 has a single-layer structure. Alternatively, the positive electrode 120 can have a multi-layer structure. The positive electrode, 1.4 μm in thickness, can be formed by depositing, for example, about 5000 Å silver (Ag), about 800 Å nickel (Ni), and 8000 Å gold (Au), consecutively, on the GaN layer 106, the first thin-film metal layer 111, or the second thin-film metal layer 112. A light-emitting semiconductor device with sufficiently high reflectivity and luminous efficiency can be obtained by the positive electrode having this multi-layer structure.

(Third Embodiment)

FIG. 4 illustrates a sectional view of a flip tip type of light-emitting semiconductor device 300. The semiconductor device 300 has a sapphire substrate 101 which

has a buffer layer 102 made of nitride aluminum (AlN) having a thickness of 200 Å and an n^+-layer 103 having a thickness of 4.0 μm and a high carrier concentration successively thereon.

And an emission layer 104 having a multi quantum-well (MQW) structure made of GaN and $Ga_{0.8}In_{0.2}N$ is formed on the n^+-layer 103. A Mg-doped p-layer 105 made of $Al_{0.15}Ga_{0.85}N$ having a thickness of 600 Å is formed on the emission layer 104. Further, a Mg-doped p-layer 106 made of GaN having a thickness of 1500 Å is formed on the p-layer 105.

A positive electrode 120, which may be also referred to as a multiple positive electrode 120 hereinafter, is formed by a metal deposit on the p-layer 106 and a negative electrode 140 is formed on the n^+-layer 103. The multiple positive electrode 120 is made of a three-layer structure, having a first positive electrode layer 121 which is adjacent to the p-layer 106, a second positive electrode layer 122 formed on the first positive electrode layer 121, and a third positive electrode layer 123 formed on the second positive electrode layer 122.

The first positive electrode layer 121 is a metal layer adjacent to the p-layer 106, which is made of rhodium (Rh) and has a thickness about 0.1 μm. The second positive electrode layer 122 is a metal layer made of gold (Au), having a thickness about 1.2 μm. The third positive electrode layer 123 is a metal layer made of titanium (Ti), having a thickness about 20 Å.

A negative electrode 140 having a multi-layer structure is formed on an exposed portion of the n^+-layer 103 of high carrier concentration. The multi-layer structure is comprising following five layers: about 175 Å in thickness of vanadium (V) layer 141; about 1000 Å in thickness of aluminum (Al) layer 142; about 500 Å in thickness of vanadium (V) 143; about 5000 Å in thickness of nickel (Ni) layer 144; and about 8000 Å in thickness of gold (Au) layer 145.

A protection layer 130 made of SiO_2 film is formed between the multiple positive electrode 120 and the negative electrode 140. The protection layer 130 covers a portion of the n^+-layer 103 exposed to form the negative electrode 140, sides of the emission layer 104, the p-layer 105, and the p-layer 106 exposed by etching, a portion of an upper surface of the p-layer 106, sides of the first positive electrode layer 121, the second positive electrode layer 122, and the third positive electrode layer 123, and a portion of an upper surface of the third positive electrode layer 123. A thickness of the protection layer 130 covering a portion of the upper surface of the third positive electrode layer 123 is 0.5 μm.

FIG. 5A shows a table comparing luminous intensities of the light-emitting semiconductor device 300 explained above with the light-emitting semiconductor device 400 of prior art. As shown in FIG. 5A, the present invention can improve the luminous efficiency by about 30 to 40 % compared

with the prior art.

Because the structure of the flip tip type of light-emitting semiconductor device 300 allows itself to have a high luminous intensity and durability, the protection layer 130 can be omitted in considerable area and both the positive and the negative electrodes can use wider area to connect to an external electrode. By forming a bump by solder or a gold ball directly on the positive and the negative electrodes, the light-emitting semiconductor device 300 is inverted and can be directly connected with a circuit board.

Further, the light-emitting semiconductor device 300 can also be connected with an external electrode by a wire bonding.

In the third embodiment, the multiple positive electrode 120 has a thickness about 1.3 μm. Alternatively, the thickness of the multiple positive electrode 120 can be in the range of 0.11 μm to 10 μm. When the thickness of the multiple positive electrode 120 is less than 0.11 μm, a light reflectivity becomes insufficient, and a firm adhesion to connecting materials such as a bump, a gold ball, etc. cannot be obtained. And when the thickness of the multiple positive electrode 120 is more than 10 μm, too much time and materials for deposit are required, which means that the thickness is of no use concerning a production cost performance.

In the third embodiment, the first positive electrode

layer 121 has a thickness about 0.1 μm. Alternatively, the thickness of the first positive electrode layer 121 can be in the range of 0.01 μm to 5 μm. The thickness of the first positive electrode layer 121 should be more preferably in the range of 0.05 μm to 1 μm. When the thickness of the first positive electrode layer 121 is too small, a light reflectivity becomes insufficient, and when too large, too much time and materials for deposit are required, which means that the thickness is of no use concerning a production cost performance.

In the third embodiment, the second positive electrode layer 122 has a thickness about 1.2 μm. Alternatively, the thickness of the second positive electrode layer 122 can be in the range of 0.03 μm to 5 μm. The thickness of the second positive electrode layer 122 should be preferably in the range of 0.1 μm to 5 μm, more preferably 0.2 μm to 3 μm, and further more preferably, 0.5 μm to 2 μm. When the thickness of the second positive electrode layer 122 is too small, a firm adhesion to connecting materials such as a bump, a gold ball, etc. cannot be obtained. And when too large, too much time and materials for deposit are required, which means that the thickness is not preferable for both the second positive electrode layer 122 and the negative electrode 140, concerning a production cost performance.

In the third embodiment, the third positive electrode layer 123 has a thickness about 20 Å. Alternatively, the thickness of the third positive electrode layer 123 can be

in the range of 3 Å to 1000 Å. The thickness of the third positive electrode layer 123 should be preferably in the range of 5 Å to 1000 Å, more preferably 10 Å to 500 Å, and further more preferably, 15 Å to 100 Å. When the thickness of the third positive electrode layer 123 is too small, an adhesion to the protection layer 130 is weakened, and when too large, a resistivity becomes too large.

In the third embodiment, the third positive electrode layer 123 is made of titanium (Ti). Alternatively, the third positive electrode layer 123 can be made of titanium (Ti) or chromium (Cr), or an alloy including at least one of these metals.

FIG. 6 illustrates a table showing characteristics of metals used in the first positive electrode layer 121. Each evaluation items ① through ⑥ are as follows:

① REFLECTIVITY: a degree of reflectivity of visible (violet, blue, and green) rays whose wavelength is in the range of 380 nm to 550 nm, when a certain quantity of light is emitted by the emission layer 104;

② CONTACT RESISTANCE (DRIVING VOLTAGE): a degree of driving voltage of the light-emitting semiconductor device associated with a contact resistance to the GaN layer;

③ ADHESIVENESS TO GAN LAYER: a degree of generation frequency of a failure examined by a predetermined endurance test;

④ CORROSION RESISTSANCE: an evaluation by characteristics of each metal;

⑤ CHARACTERISTICS STABILITY AFTER FORMING Au: an evaluation by an increasing of driving voltage with laps of time after forming the second positive electrode layer 122 made of gold (Au) formed in the light-emitting semiconductor device 300, and a decreasing of reflectivity of visible rays;

⑥ TOTAL EVALUATION (MASS PRODUCTION): a total evaluation based on items ① to ⑤ described above, concerning a mass production of the light-emitting semiconductor device of this invention.

Especially, with respect to a flip tip type of light-emitting semiconductor device, the evaluations should be better than GOOD (○) at both items ① and ② for a mass production of the light-emitting semiconductor device. Accordingly, the list shown in FIG. 6 shows a usefulness of the present device.

Although rhodium (Rh) is inferior a little to silver (Ag) concerning reflectivity (item ①), it has the same or superior characteristics in items ② to ⑤, compared with other metals. So rhodium (Rh) is proved to be one of the best metals to form one of the positive electrode and the first positive electrode layer.

Also, ruthenium (Ru) has a similar or close characteristics to rhodium (Rh). So it is also proved to be

one of the best metals to form one of the positive electrode and the first positive electrode layer.

(Fourth Embodiment)

FIG. 9 shows a plan view of a light-emitting semiconductor device 500, an embodiment of the light-emitting semiconductor device 300 shown in FIG. 4 of the present invention. Because the light-emitting semiconductor 500 has the almost same structure as that of the light-emitting device 300, each layers has the same number and uses the same metal as that of each layers in FIG. 4.

Then an aging variation for a luminous intensity of the light-emitting semiconductor device 500 has been measured. FIG. 5B shows a table comparing aging variations for luminous intensities of the light-emitting semiconductor device 500 and the light-emitting semiconductor device 400 of prior art. As shown in FIG. 5B, with respect to the luminous intensity, the present invention can hold 95 % of the initial value after 100 hours and 90 % after 1000 hours, while the light-emitting semiconductor device 400 can only hold 90 % of the initial value after 100 hours and 85 % after 1000 hours. Accordingly, the present invention can improve a durability compared with the light-emitting semiconductor device 400 of prior art.

Because the structure of the flip tip type of light-emitting semiconductor device 500 allows itself to have a high luminous intensity and durability, the protection layer

130 can be omitted in considerable area and both the positive and the negative electrodes can use wider area to connect to an external electrode. As shown FIG. 9, the negative electrode and the positive electrode can occupy over 10 % and over 40 % of the upper area of the light-emitting semiconductor device 500, respectively. As a result, a connection with an external electrode cannot be restricted to a wire bonding. Alternatively, the electrodes can be connected to an external electrode by forming a bump by solder or a gold ball directly on the positive and the negative electrodes, or the light-emitting semiconductor device 500 is inverted and can be directly connected with a circuit board.

In the fourth embodiment, the multiple positive electrode 120 has a thickness about 1.5 μm. Alternatively, the thickness of the multiple positive electrode 120 can be in the range of 0.11 μm to 10 μm. When the thickness of the multiple positive electrode 120 is less than 0.11 μm, a light reflectivity becomes insufficient, and a firm adhesion to connecting materials such as bump, a gold ball, etc. cannot be obtained. And when the thickness of the multiple positive electrode 120 is more than 10 μm, too much time and materials for deposit are required, which means that the thickness is of no use concerning a production cost performance.

In the fourth embodiment, the first positive electrode layer 121 has a thickness about 0.3 μm. Alternatively, the

thickness of the first positive electrode layer 121 can be in the range of 0.01 μm to 5 μm. The thickness of the first positive electrode layer 121 should be more preferably in the range of 0.05 μm to 1 μm. When the thickness of the first positive electrode layer 121 is too small, a light reflectivity becomes insufficient, and when too large, too much time and materials for deposit are required, which means that the thickness is of no use concerning a production cost performance.

In the fourth embodiment, the second positive electrode layer 122 has a thickness about 1.2 μm. Alternatively, the thickness of the second positive electrode layer 122 can be in the range of 0.03 μm to 5 μm. The thickness of the second positive electrode layer 122 should be preferably in the range of 0.05 μm to 3 μm, 0.1 μm to 5 μm, and more preferably, 0.2 μm to 3 μm, and further more preferably, 0.5 μm to 2 μm. When the thickness of the second positive layer 122 is too small, a firm adhesion to connecting materials such as a bump, a gold ball, etc. cannot be obtained. And when too large, too much time and materials for deposit are required, which means that the thickness is not preferable for both the second positive electrode layer 122 and the negative electrode 140, concerning a production cost performance.

In the fourth embodiment, the third positive electrode layer 123 has a thickness about 20 Å. Alternatively, the thickness of the third metal layer 112 can be in the range

of 3 Å to 1000 Å. The thickness of the third positive electrode layer 123 should be preferably in the range of 5 Å to 1000 Å, more preferably, 10 Å to 500 Å, and further more preferably, 15 Å to 100 Å. When the thickness of the third positive electrode layer 123 is too small, an adhesion to the protection layer 130 is weakened, and when too large, a resistivity becomes too large.

In the fourth embodiment, the third positive electrode layer 123 is made of titanium (Ti). Alternatively, the third positive electrode layer 123 can be made of chromium (Cr).

(Fifth Embodiment)

FIG. 10 illustrates a sectional view of a flip tip type of light-emitting semiconductor device 600. The semiconductor device 600 has a sapphire substrate 101 which has a buffer layer 102 made of nitride aluminum (AlN) having a thickness of 200 Å and an n^+-layer 103 having a thickness of 4.0 μm and a high carrier concentration successively thereon.

And an emission layer 104 having a multi quantum-well (MQW) structure made of GaN and $Ga_{0.8}In_{0.2}N$ is formed on the n^+-layer 103. A Mg-doped p-layer 105 made of $Al_{0.15}Ga_{0.85}N$ having a thickness of 600 Å is formed on the emission layer 104. Further, a Mg-doped p-layer 106 made of GaN having a thickness of 1500 Å is formed on the p-layer 105.

A positive electrode 120, which may be also referred to

as a multiple positive electrode 120 hereinafter, is formed by a metal deposit on the p-layer 106 and a negative electrode 140 is formed on the n^+-layer 103. The multiple positive electrode 120 is made of a three-layer structure, having a first positive electrode layer 121 which is adjacent to the p-layer 106, a second positive electrode layer 122 formed on the first positive electrode layer 121, and a third positive electrode layer 123 formed on the second positive electrode layer 122.

The first positive electrode layer 121 is a metal layer adjacent to the p-layer 106, which is made of rhodium (Rh) and has a thickness about 3000 Å. The second positive electrode layer 122 is a metal layer made of titanium (Ti), having a thickness about 100 Å. The third positive electrode layer 123 is a metal layer made of gold (Au), having a thickness about 500 Å.

A negative electrode 140 having a multi-layer structure is formed on an exposed portion of the n^+-layer 103 of high carrier concentration. The multi-layer structure is comprising following five layers: about 175 Å in thickness of vanadium (V) layer 141; about 1000 Å in thickness of aluminum (Al) layer 142; about 500 Å in thickness of vanadium (V) 143; about 5000 Å in thickness of nickel (Ni) layer 144; and about 8000 Å in thickness of gold (Au) layer 145.

A protection layer 130 made of SiO_2 film is formed between the multiple positive electrode 120 and the negative

electrode 140. The protection layer 130 covers a portion of the n^+-layer 103 exposed to form the negative electrode 140, sides of the emission layer 104, the p-layer 105, and the p-layer 106 exposed by etching, a portion of an upper surface of the p-layer 106, sides of the first positive electrode layer 121, the second positive electrode layer 122, and the third positive electrode layer 123, and a portion of an upper surface of the third positive electrode layer 123. A thickness of the protection layer 130 covering a portion of the upper surface of the third positive electrode layer 123 is 0.5 μm.

The present invention can improve the luminous efficiency by about 30 to 40 % compared with the prior art.

Because the structure of the flip tip type of light-emitting semiconductor device 600 allows itself to have a high luminous intensity and durability, the protection layer 130 can be omitted in considerable area and both the positive and the negative electrodes can use wider area to connect to an external electrode. By forming a bump by solder or a gold ball directly on the positive and the negative electrodes, the light-emitting semiconductor device 600 is inverted and can be directly connected with a circuit board.

Further, the light-emitting semiconductor device 600 can also be connected with an external electrode by a wire bonding.

In the fifth embodiment, the multiple positive

electrode 120 has a thickness about 0.36 μm. Alternatively, the thickness of the multiple positive electrode 120 can be in the range of 0.11 μm to 10 μm. When the thickness of the multiple positive electrode 120 is less than 0.11 μm, a light reflectivity becomes insufficient, and a firm adhesion to connecting materials such as a bump, a gold ball, etc. cannot be obtained. And when the thickness of the multiple positive electrode 120 is more than 10 μm, too much time and materials for deposit are required, which means that the thickness is of no use concerning a production cost performance.

In the fifth embodiment, the first positive electrode layer 121 has a thickness about 3000 Å. Alternatively, the thickness of the first positive electrode layer 121 can be in the range of 0.01 μm to 5 μm. The thickness of the first positive electrode layer 121 should be more preferably in the range of 0.05 μm to 1 μm. When the thickness of the first positive electrode layer 121 is too small, a light reflectivity becomes insufficient, and when too large, too much time and materials for deposit are required, which means that the thickness is of no use concerning a production cost performance.

In the fifth embodiment, the second positive electrode layer 122 has a thickness about 100 Å. Alternatively, the thickness of the second positive electrode layer 122 can be in the range of 3 Å to 1000 Å. The thickness of the second positive electrode layer 122 should be preferably in the

range of 5 Å to 1000 Å, and more preferably, 5 Å to 500 Å, and further more preferably, 15 Å to 100 Å. When the thickness of the second positive electrode layer 122 is too small, a firm adhesion to connecting materials such as a bump, a gold ball, etc. cannot be obtained. And when too large, too much time and materials for deposit are required, which means that the thickness is not preferable for both the second positive electrode layer 122 and the negative electrode 140, concerning a production cost performance.

In the fifth embodiment, the third positive electrode layer 123 has a thickness about 500 Å. Alternatively, the thickness of the third positive electrode layer 123 can be in the range of 0.03 μm to 5 μm. The thickness of the third positive electrode layer 123 should be preferably in the range of 0.05 μm to 3 μm, 0.1 μm to 5 μm, more preferably, 0.2 μm to 3 μm, and further more preferably, 0.5 μm to 2 μm. When the thickness of the third positive electrode layer 123 is too small, an adhesion to the protection layer 130 is weakened, and when too large, a resistivity becomes too large.

In the fifth embodiment, the third positive electrode layer 123 is made of gold (Au). Alternatively, a fourth positive electrode 124 made of one of titanium (Ti), chromium (Cr), and an alloy including at least one of these metals can be formed on the third positive electrode layer 123 with the width of the third positive electrode layer of the third embodiment.

With respect to the structure of the layers of the electrodes in the first to fifth embodiments, physical and chemical composition of each layers in the light-emitting semiconductor device is shown at the instant time of deposition. It is needless to mention that solid solutions or chemical compounds are formed between each layers by physical or chemical treatments such as a heat treatment to obtain a firmer adhesion or to lower a contact resistivity.

In the first to fifth embodiments, the emission layer 104 has a MQW (multi-quantum well) structure. Alternatively, the emission layer 104 can have a SQW (single-quantum well) structure or a homozygous structure. Also, a III group nitride compound semiconductor layer (inclusive of a buffer layer) of the light-emitting semiconductor device in the present invention can be formed of one of a quaternary, ternary and binary layer compound $Al_xGa_yIn_{1-x-y}N$ ($0 \leqq x \leqq 1$, $0 \leqq y \leqq 1$, $0 \leqq x+y \leqq 1$).

Alternatively, metal nitrides such as titanium nitride (TiN), hahnium nitride (HfN) or metal oxide such as zinc oxide (ZnO), magnesium oxide (MgO), manganese oxide (MnO) can be used to form the buffer layer.

In the embodiments, magnesium (Mg) is used as a p-type impurity. Alternatively, group II elements such as beryllium (Be) or zinc (Zn) can be used. Further, to lower a resistivity of the p-type semiconductor layer doped with a p-type impurity described above, activates treatments such

as radiation of electron rays or annealing can be executed.

In the embodiments, the n^+-layer 103 of high carrier intensity is made of silicon (Si) doped gallium nitride (GaN). Alternatively, these n-type semiconductor layers can be formed by doping the group III nitride compound semiconductor described above with group IV elements such as silicon (Si) or germanium (Ge), or group VI elements.

In the embodiments, sapphire is used for the substrate. Alternatively, silicon carbide (SiC), zinc oxide (ZnO), magnesium oxide (MgO), or manganese oxide (MnO) can be used to form the substrate.

While the invention has been described in connection with what are presently considered to be the most practical and preferred embodiments, it is to be understood that the invention is not to be limited to the disclosed embodiments, but on the contrary, is intended to cover various modifications and equivalent arrangements included within the spirit and scope of the appended claims.

WHAT IS CLAIMED IS:

1. A flip tip type of light-emitting semiconductor device comprising:

a substrate;

group III nitride compound semiconductor layers formed on said substrate; and

a positive electrode including at least one layer of a first positive electrode layer which is formed on or above a p-type semiconductor layer and reflects light toward said substrate, said first positive electrode layer being made of at least one of silver (Ag), rhodium (Rh), ruthenium (Ru), platinum (Pt), palladium (Pd), and an alloy including at least one of these metals.

2. A flip tip type of light-emitting semiconductor device using group III nitride compound according to claim 1, wherein said positive electrode has a multi-layer structure made of a plural kinds of metals.

3. A flip tip type of light-emitting semiconductor device using group III nitride compound according to claim 1, further comprising a first thin-film metal layer, which is made of at least one of cobalt (Co), nickel (Ni), and an alloy including at least one of these metals, formed between said p-type semiconductor layer and said first positive electrode layer.

4. A flip tip type of light-emitting semiconductor device using group III nitride compound according to claim 2, further comprising a first thin-film metal layer, which is made of at least one of cobalt (Co), nickel (Ni), and an alloy including at least one of these metals, formed between said p-type semiconductor layer and said first positive electrode layer.

5. A flip tip type of light-emitting semiconductor device using group III nitride compound according to claim 3, wherein a thickness of said first thin-film metal layer is in the range of 2 Å to 200 Å.

6. A flip tip type of light-emitting semiconductor device using group III nitride compound according to claim 4, wherein a thickness of said first thin-film metal layer is in the range of 2 Å to 200 Å.

7. A flip tip type of light-emitting semiconductor device using group III nitride compound according to claim 3, further comprising a second thin-film metal layer, which is made of at least one of gold (Au) and an alloy including gold (Au), formed between said first thin-film metal layer and said first positive electrode layer.

8. A flip tip type of light-emitting semiconductor device using group III nitride compound according to claim

4, further comprising a second thin-film metal layer, which is made of at least one of gold (Au) and an alloy including gold (Au), formed between said first thin-film metal layer and said first positive electrode layer.

9. A flip tip type of light-emitting semiconductor device using group III nitride compound according to claim 7, wherein a thickness of said second thin-film metal layer is in the range of 10 Å to 500 Å.

10. A flip tip type of light-emitting semiconductor device using group III nitride compound according to claim 8, wherein a thickness of said second thin-film metal layer is in the range of 10 Å to 500 Å.

11. A flip tip type of light-emitting semiconductor device using group III nitride compound according to claim 1, wherein a thickness of said first positive electrode layer is in the range of 0.01 μm to 5 μm.

12. A flip tip type of light-emitting semiconductor device using group III nitride compound according to claim 1, said positive electrode further comprising a second positive electrode layer, which is made of at least one of gold (Au) and an alloy including gold (Au), formed on said first positive electrode layer.

13. A flip tip type of light-emitting semiconductor device using group III nitride compound according to claim 12, wherein a thickness of said second positive electrode layer is in the range of 0.03 μm to 5 μm.

14. A flip tip type of light-emitting semiconductor device using group III nitride compound according to claim 1, said positive electrode further comprising a third positive electrode layer, which is made of at least one of titanium (Ti), chromium (Cr), and an alloy including at least one of these metals, formed on said first positive electrode layer.

15. A flip tip type of light-emitting semiconductor device using group III nitride compound according to claim 12, said positive electrode further comprising a third positive electrode layer, which is made of at least one of titanium (Ti), chromium (Cr), and an alloy including at least one of these metals, formed on said second positive electrode layer.

16. A flip tip type of light-emitting semiconductor device using group III nitride compound according to claim 15, wherein a thickness of said third positive electrode layer is in the range of 3 Å to 1000 Å.

17. A flip tip type of light-emitting semiconductor

device comprising:

a substrate;

group III nitride compound semiconductor layers formed on said substrate; and

a positive electrode which is formed on or above a p-type semiconductor layer and reflects light toward said substrate, wherein said positive electrode has a three-layer structure comprising:

a first positive electrode layer which is made of at least one of rhodium (Rd), ruthenium (Ru), and an alloy including at least one of these metals;

a second positive electrode layer which is made of at least one of gold (Au) and an alloy including gold (Au), and formed directly on said first positive electrode layer; and

a third positive electrode layer which is made of at least one of titanium (Ti), chromium (Cr), and an alloy including at least one of these metals, formed directly on said second positive electrode layer.

18. A flip tip type of light-emitting semiconductor device using group III nitride compound according to claim 17, wherein thicknesses of said first, second, and third positive electrode layers are in the range of 0.02 μm to 2 μm, 0.05 μm to 3 μm, and 5 Å to 500 Å, respectively.

19. A flip tip type of light-emitting semiconductor device using group III nitride compound according to claim

17, further comprising a first thin-film metal layer, which is made of at least one of cobalt (Co), nickel (Ni), and an alloy including at least one of these metals, formed between said p-type semiconductor layer and said first positive electrode layer.

20. A flip tip type of light-emitting semiconductor device using group III nitride compound according to claim 17, further comprising a second thin-film metal layer, which is made of at least one of gold (Au) and an alloy including gold (Au), formed between said first thin-film metal layer and said first positive electrode layer.

21. A flip tip type of light-emitting semiconductor device using group III nitride compound according to claim 17, wherein an insulated protective film which is made of one of silicon oxide (SiO_2), silicon nitride (Si_xN_y), titanium compound (Ti_xN_y, etc.) and polyamide, is formed directly on said third positive electrode layer.

22. A flip tip type of light-emitting semiconductor device comprising:

a substrate;

group III nitride compound semiconductor layers formed on said substrate; and

a positive electrode which is formed on or above a p-type semiconductor layer and reflects light toward said

substrate, wherein said positive electrode has a three-layer structure comprising:

a first positive electrode layer which is made at least one of rhodium (Rd), ruthenium (Ru), and an alloy including at least one of these metals;

a second positive electrode layer which is made of at least one of titanium (Ti), chromium (Cr), and an alloy including at least one of these metals, and formed directly on said first positive electrode layer; and

a third positive electrode layer which is made of at least one of gold (Au) and an alloy including gold (Au), formed directly on said second positive electrode layer.

23. A flip tip type of light-emitting semiconductor device using group III nitride compound according to claim 22, wherein thicknesses of said first, second, and third positive electrode layers are in the range of 0.02 μm to 2 μm, 5 Å to 500 Å, and 0.05 μm to 3 μm, respectively.

24. A flip tip type of light-emitting semiconductor device using group III nitride compound according to claim 22, wherein an insulated protective film which is made of one of silicon oxide (SiO_2), silicon nitride (Si_xN_y), titanium compound (Ti_xN_y, etc.) and polyamide, is formed directly on said third positive electrode layer.

25. A flip tip type of light-emitting semiconductor

device using group III nitride compound according to claim 22, further comprising a fourth positive electrode layer made of at least one of titanium (Ti), chromium (Cr), and an alloy including at least one of these metals, formed directly on said third positive electrode layer.

26. A flip tip type of light-emitting semiconductor device using group III nitride compound according to claim 25, wherein an insulated protective film which is made of one of silicon oxide (SiO_2), silicon nitride (Si_xN_y), titanium compound (Ti_xN_y, etc.) and polyamide, is formed directly on said fourth positive electrode layer.

ABSTRACT OF THE DISCLOSURE

A flip tip type of light-emitting semiconductor device using group III nitride compound comprising a thick positive electrode. The positive electrode, which is made of at least one of silver (Ag), rhodium (Rh), ruthenium (Ru), platinum (Pt) and palladium (Pd), and an alloy including at least one of these metals, is adjacent to a p-type semiconductor layer, and reflect light toward a sapphire substrate. Accordingly, a positive electrode having a high reflectivity and a low contact resistance can be obtained. A first thin-film metal layer, which is made of cobalt (Co) and nickel (Ni), or any combinations of including at least one of these metals, formed between the p-type semiconductor layer and the thick electrode, can improve an adhesion between a contact layer and the thick positive electrode. A thickness of the first thin-film metal electrode should be preferably in the range of 2 Å to 200 Å, more preferably 5 Å to 50 Å. A second thin-film metal layer made of gold (Au) can further improve the adhesion.

FIG. 1

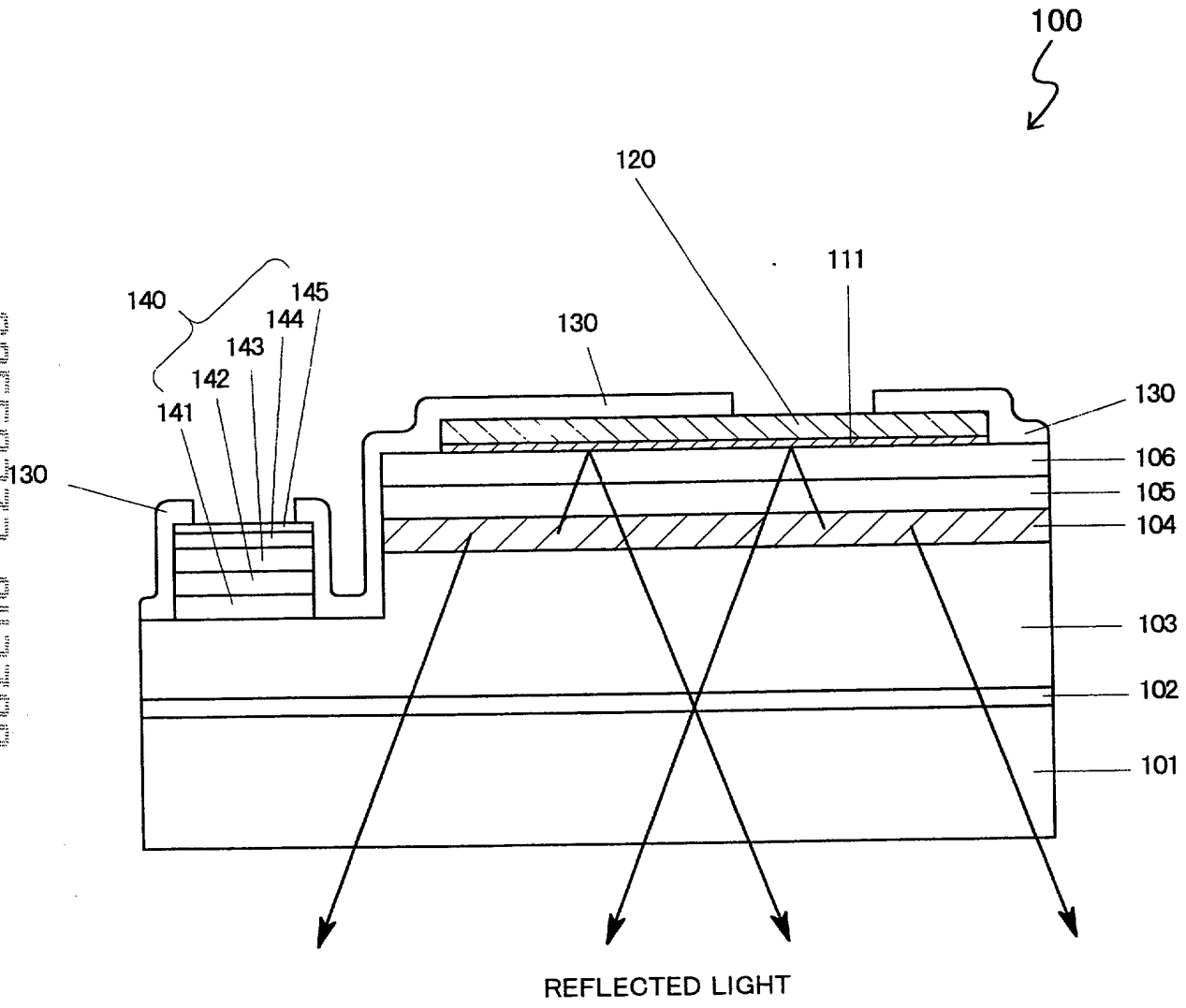
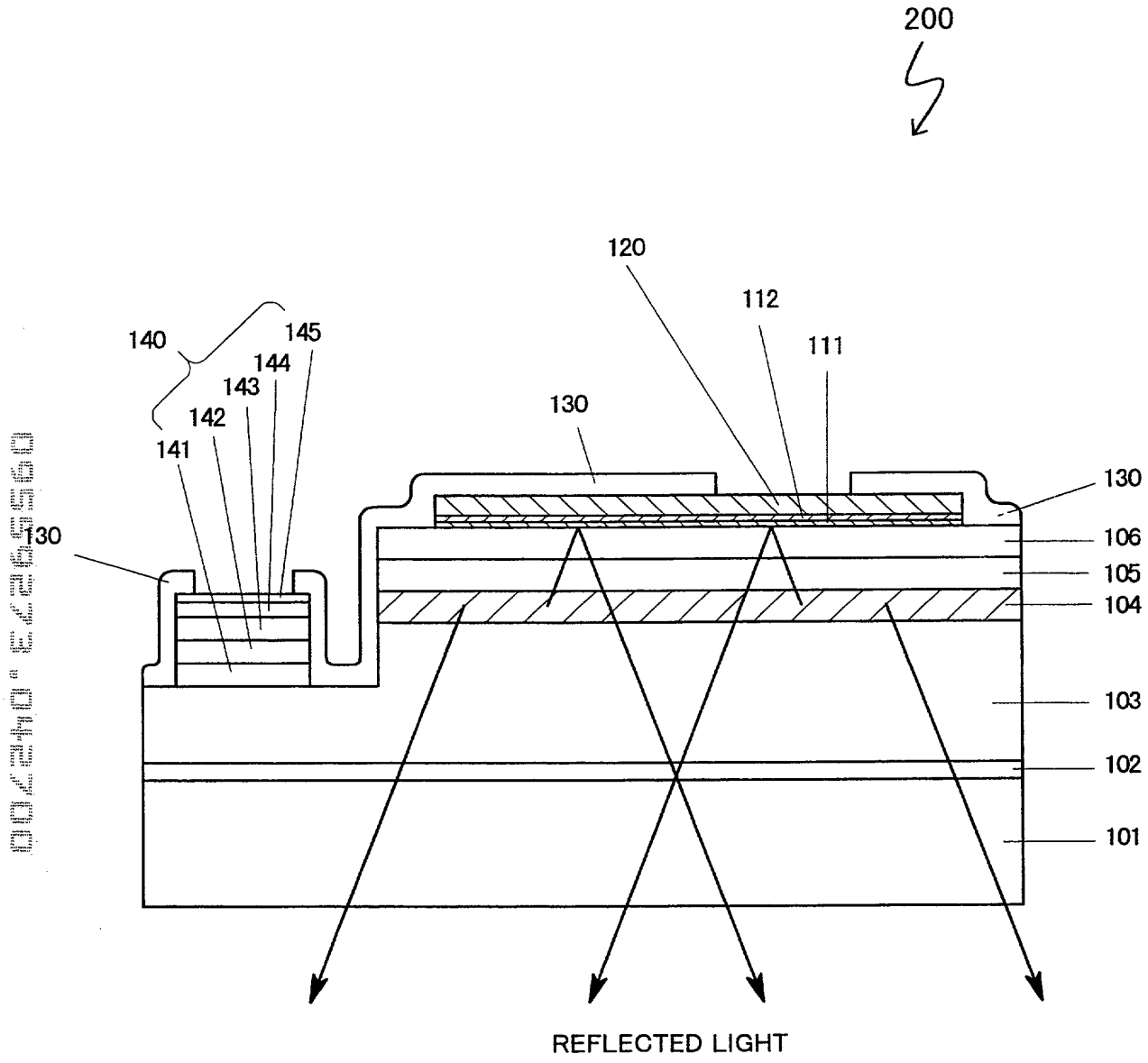

100
120
111
140
145
144
143
142
141
130
130
130
106
105
104
103
102
101
REFLECTED LIGHT

FIG. 2


200
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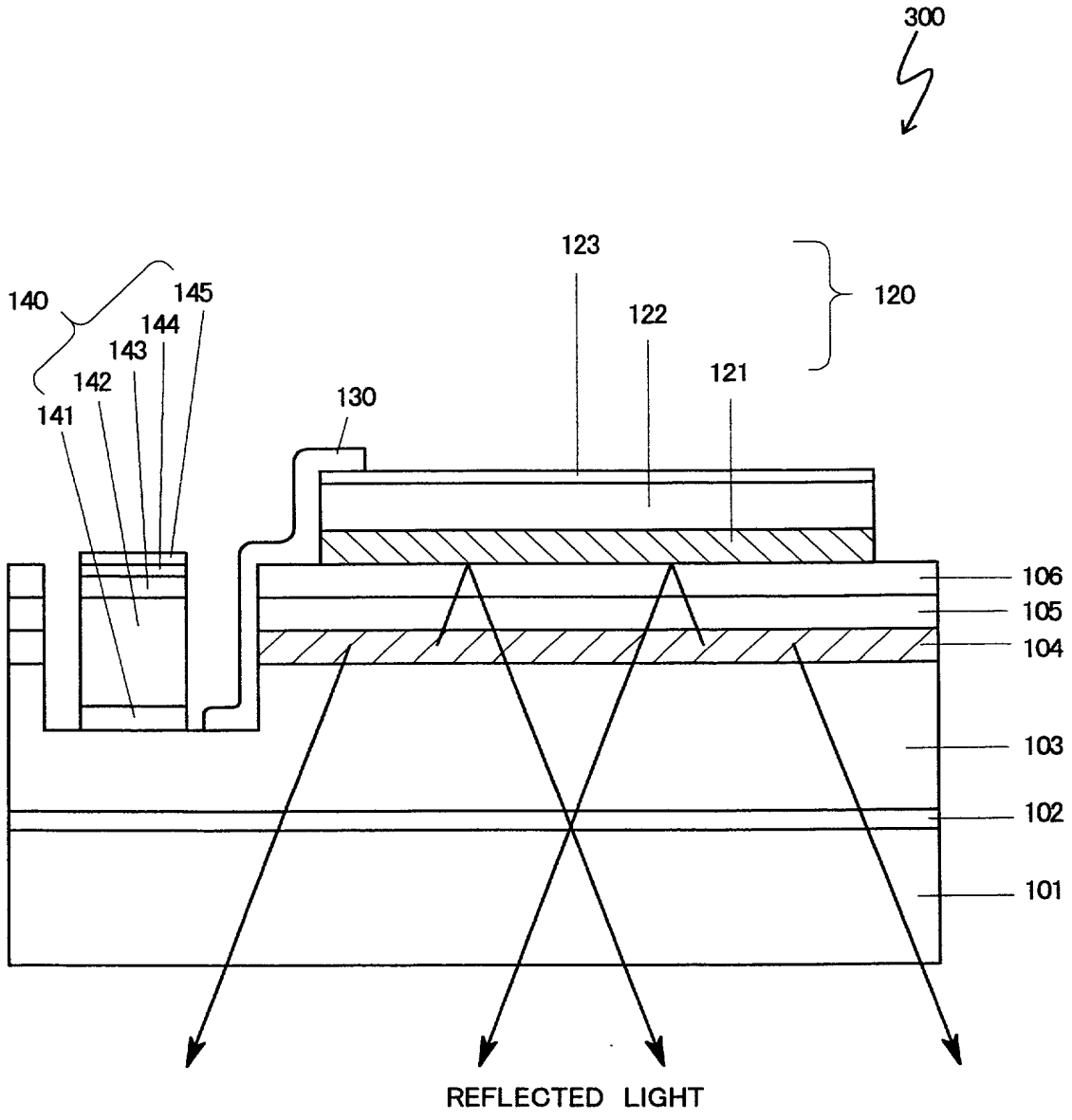
REFLECTED LIGHT

FIG. 3

ITEM	TECHNOLOGY DIVISION	STRUCTURE	POSITIVE ELECTRODE	FIRST THIN-FILM METAL LAYER	SECOND THIN-FILM METAL LAYER	RELATIVE LUMINOUS INTENSITY	ADHESIVENESS
1	PRIOR ART	LIGHT-EMITTING DEVICE 400	Co (3000 Å)	–	–	100	◎
2			Ni (3000 Å)	–	–	100	◎
3	PRESENT INVENTION	LIGHT-EMITTING DEVICE 150	Ag (3000 Å)	–	–	160	○‾
3.1			Rh (3000 Å)	–	–	140	◎
4		LIGHT-EMITTING DEVICE 100	Ag (3000 Å)	Co (10 Å)	–	150	○
5			Rh (3000 Å)	Co (10 Å)	–	130	○
6			Pt (3000 Å)	Co (10 Å)	–	110	○
7			Pd (3000 Å)	Co (10 Å)	–	110	○
8		LIGHT-EMITTING DEVICE 200	Ag (3000 Å)	Co (10 Å)	Au (150 Å)	150	◎

◎ : EXELLENT ○ : GOOD ○‾ : inferior than GOOD but usable

FIG. 4


300
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REFLECTED LIGHT

FIG. 5A

PRIOR ART		100
PRESENT INVENTION	Pt	130
	Rh	140

FIG. 5B

	INITIAL LUMINOUS INTENSITY	100 h LATER	1000 h LATER
PRIOR ART	100	90	85
PRESENT INVENTION	100	95	90

FIG. 6

METAL	EVALUATION ITEMS					
	①	②	③	④	⑤	⑥
Rh	◎	$\bigcirc^{+}$	$\bigcirc^{+}$	$\bigcirc^{+}$	○	◎
Pt	○	○	○	○	△	○
Ru	○	○	○	○	△	○
Ag	◎	○	△	△	△	$\bigcirc^{-}$
Pd	○	○	△	○	△	$\bigcirc^{-}$
Al	◎	△	△	△	×	△
Ni	△	○	○	○	○	△
Co	△	○	○	○	○	△
Mg	○	△	○	×	△	$\triangle^{-}$
Sn	○	×	×	△	UNIDENTIFIED	×

◎ :EXELLENT ○ :GOOD △ :MEDIOCLE × :BAD $\bigcirc^{+}$:better than ○ $\bigcirc^{-}$:worse than ○

FIG. 7 (PRIOR ART)

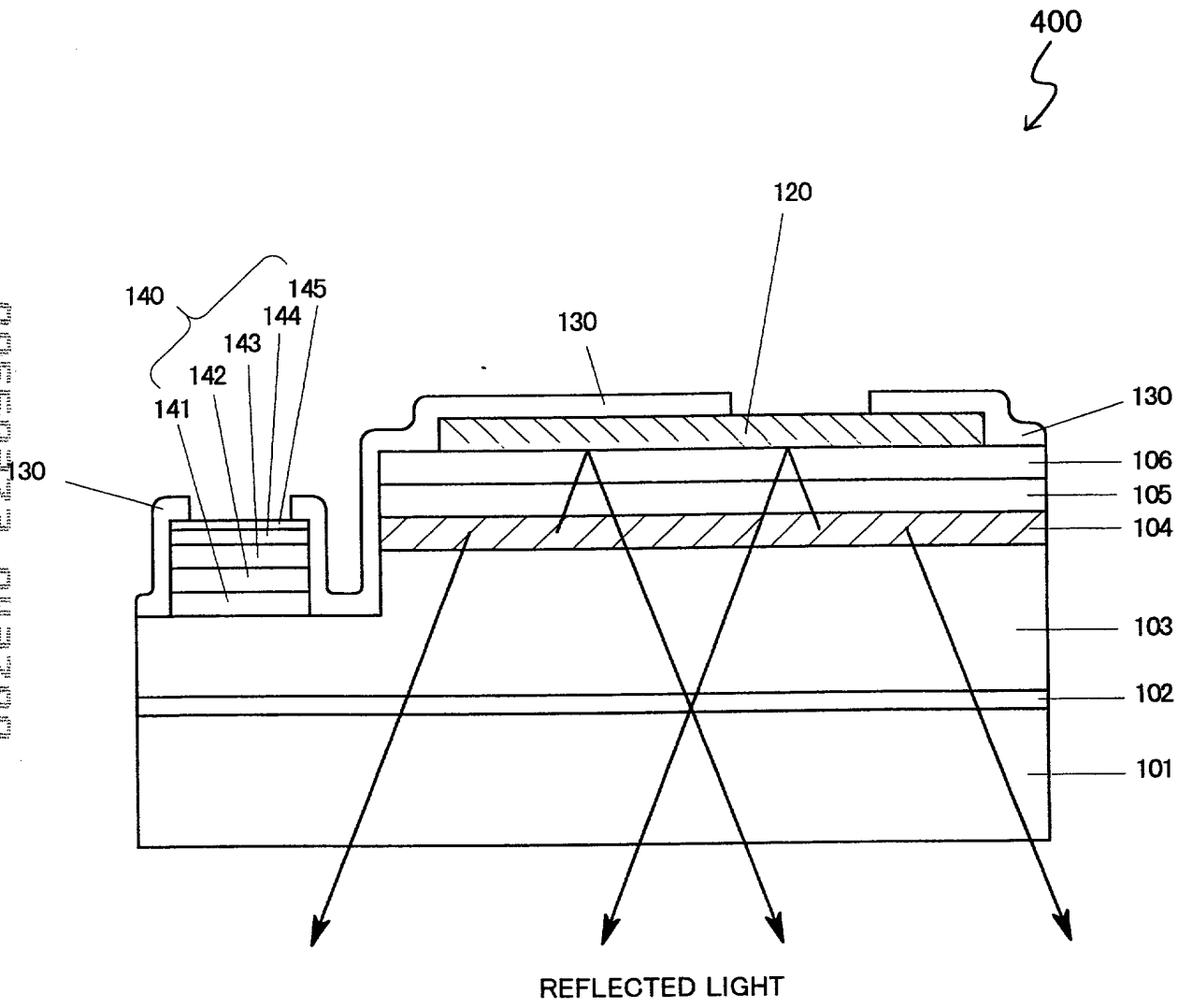
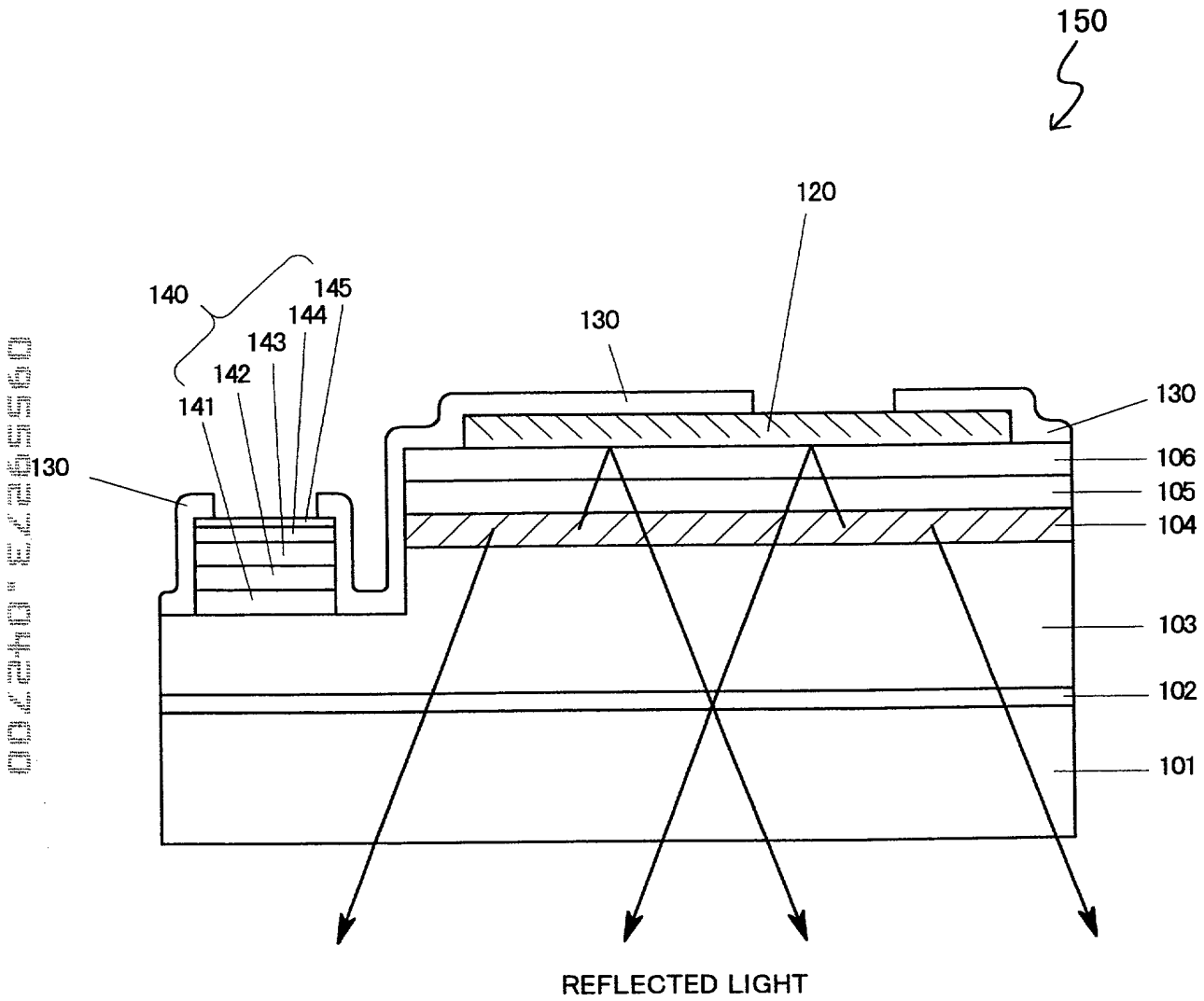


FIG. 8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REFLECTED LIGHT

FIG. 9

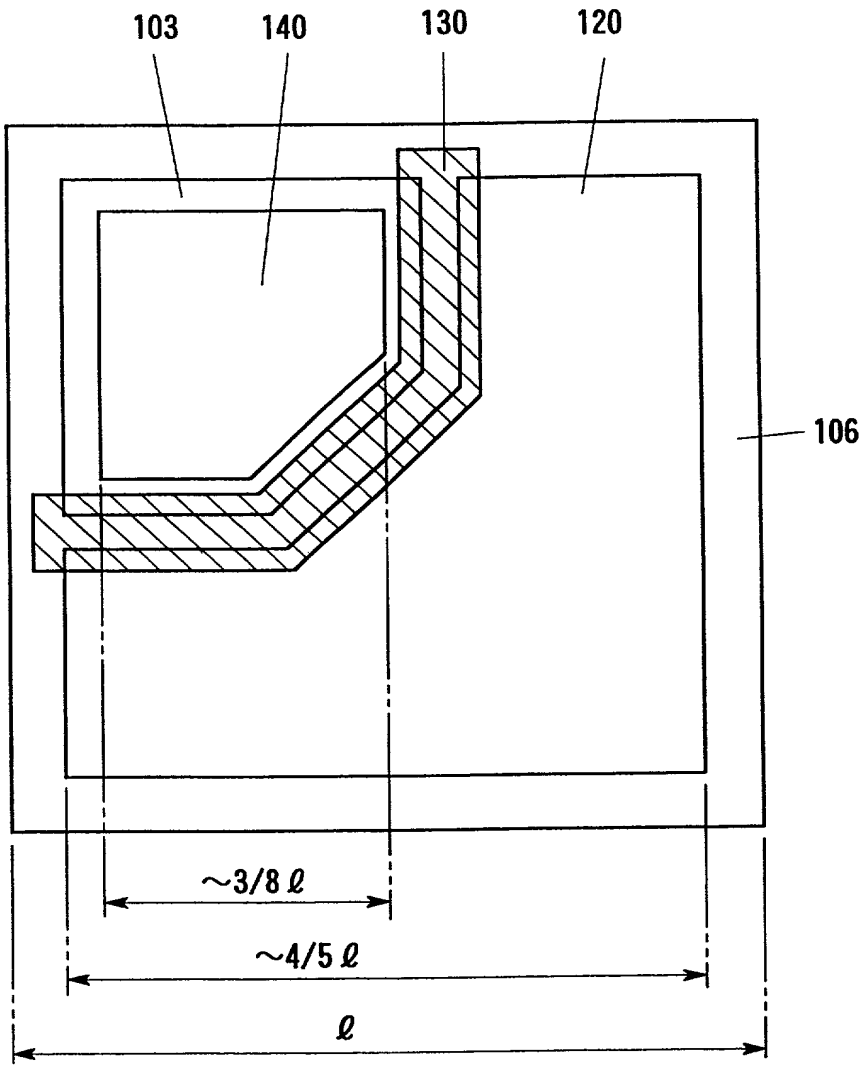
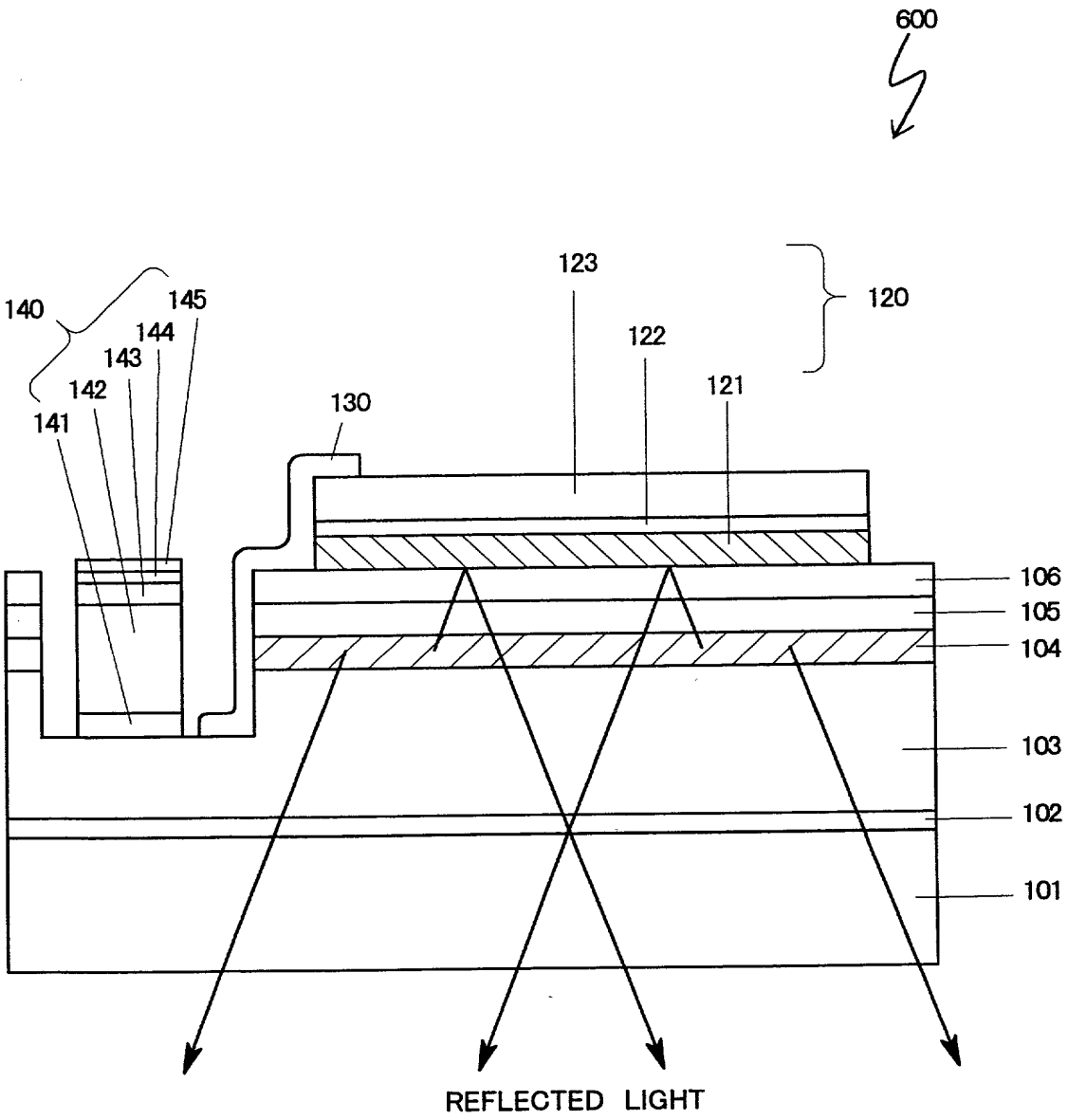


FIG. 10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REFLECTED LIGHT

ORIGINAL/SUBSTITUTE/SUPPLEMENTAL DECLARATIONS

DECLARATION AND POWER OF ATTORNEY FOR PATENT APPLICATION IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

FORM

As a below named inventor, I hereby declare that my residence, post office address and citizenship are as stated below next to my name, and I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the **INVENTION ENTITLED**

LIGHT-EMITTING SEMICONDUCTOR DEVICE USING GROUP III NITRIDE COMPOUND

the specification of which (CHECK applicable BOX(ES))

-> [ ] is attached hereto.

-> [ ] was filed on _____ as U.S. Application No. 0_/_____

)X(ES -> [ ] was filed as PCT International Application No. PCT/ _____/_____ on _____

-> -> and (if applicable to U.S. or PCT application) was amended on _____

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above. I acknowledge the duty to disclose all information known to me to be material to patentability as defined in 37 C.F.R. 1.56. I hereby claim foreign priority benefits under 35 U.S.C.119/365 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate filed by me or my assignee disclosing the subject matter claimed in this application and having a filing date (1) before that of the application on which priority is claimed, or (2) if no priority claimed, before the filing date of this application:

PRIOR FOREIGN APPLICATION(S) Number	Country	Day/MONTH/Year Filed	Date first Laid-open or Published	Date Patented or Granted	Priority Claimed Yes	No
150532/1998	JAPAN	13/May/1998			XX	
358549/1998	JAPAN	17/December/1998			XX	
56357/1999	JAPAN	4/March/1999			XX	

I hereby claim the benefit under 35 U.S.C.120/365 of all United States applications listed below and PCT international applications listed above or below and, if this is a continuation-in-part (CIP) application, insofar as the subject matter disclosed and claimed in this application is in addition to that disclosed in such prior applications, I acknowledge the duty to disclose all information known to me to be material to patentability as defined in 37 C.F.R. 1.56which became available between the filing date of each such prior application and the national or PCT international filing date of this application:

PRIOR U.S. OR PCT APPLICATION(S) Application No. (series code/serial no.)	Day/MONTH/Year Filed	Status pending, abandoned, patented

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

And I hereby appoint Cushman Darby & Cushman,L.L.P.1100 New York Avenue, N.W.,Ninth Floor, East Tower Washington, D.C.20005-3918,telephone number 861-3000(to whom all communications are to be directed), and the below-named persons (of the same address) individually and collectively my attorneys to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith and with the resulting patent, and I hereby authorize them to act and rely on instructions from and communicate directly with the person/assignee/attorney/firm/ organization who/which first sends/sent this case to them and by whom/which I hereby declare that I have consented after full disclosure to be represented unless/until I instruct Cushman, Darby & Cushman in writing to the contrary.

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Carl G. Love	18781	George M. Sirilla	18221	Chris Comuntzis	31097	G. Paul Edgell	24238
Edgar H. Martin	20534	Donald J. Bird	25323	Wallace G. Walter	27843	Lynn E. Eccleston	35861
William K. West, Jr.	22057	W. Warren Taltavull	25647	Lawrence Harbin	27644	Frederick S. Frei	27105
Kevin E. Joyce	20508	Peter W. Gowdey	25872	Paul E. White, Jr.	32011	David A. Jakopin	32995
						Mark G. Paulson	30793

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3. INVENTOR'S SIGNATURE: _____ Date _____

Inventor's Name (typed) _____ (First) _____ (Middle Initial) _____ (Family Name) _____ (Country of Citizenship)

Residence (City) _____ (State/Foreign Country) _____

Post Office Address (Include Zip Code) _____

(FOR ADDITIONAL INVENTORS, check box [ ] and attach sheet (CDC-116.2) for same information for each re signature, name, date, citizenship, residence and address.)